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Investigation of the Effects of Unidirectional Compression on the Hardness of High-Density Polyethylene Materials

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Abstract - In this study, hardness measurements were carried out by applying one-way compression to the high-density polyethylene (HDPE) material at different rates. The amount of deformation was made at room conditions approximately at 23 °C and 50% humidity with 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% strain ratios. Compression processes were made on 3 mm thick plate samples. The pressing direction was carried out in the direction of thickness. The hardness and stress values of the samples were determined which were subjected to compression processes. In addition, plastic deformation rates for each compression ratio were calculated. The highest hardness value was determined at a 10% compression ratio, and it was observed that the hardness values decreased with increasing compression ratios. In plastic deformation rates, the permanent deformation of 10% and 20% is very slight, and apart from these, a remarkable increase has been observed with increasing deformation rates.

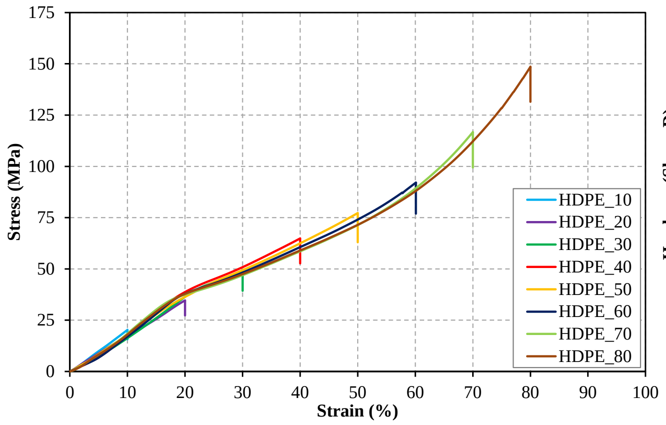
Keywords: High-density polyethylene, Compression, Deformation, Hardness, Stress

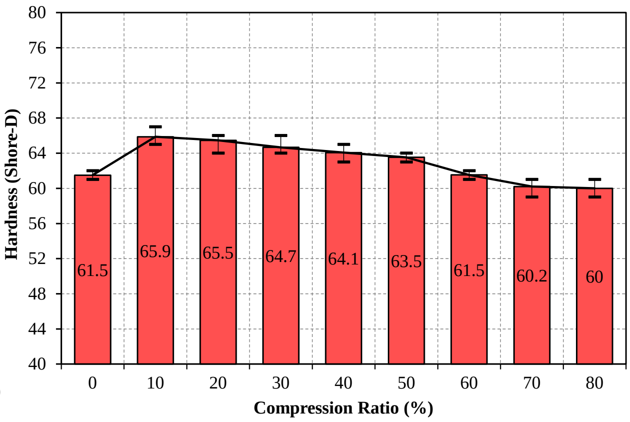
Tek Yönlü Basma İşleminin Yüksek Yoğunluklu Polietilen Malzemelerin Sertliğine Etkisinin Araştırılması

Öz - Bu çalışmada yüksek yoğunluklu polietilen (HDPE) malzemeye farklı oranlarda tek yönlü basma işlemi uygulanarak sertlik ölçümleri gerçekleştirilmiştir. Şekil değişim miktarları %10, %20, %30, %40, %50, %60, %70 ve %80 oranlarında oda şartlarında yaklaşık 23 °C and %50 nemde gerçekleştirilmiştir. Basma işlemleri plaka şeklinde 3 mm kalınlığında numunelere yapılmıştır. Basma yönü kalınlık doğrultusunda gerçekleştirilmiştir. Basma işlemleri yapılan numunelerin sertlik değerleri ve gerilme değerleri tespit edilmiştir. Ayrıca her bir sıkıştırma oranı için plastik deformasyon oranları hesaplanmıştır. %10 basma oranında en yüksek sertlik değeri tespit edilmiş olup artan basma oranlarında sertlik değerlerinin düştüğü gözlemlenmiştir. Plastik deformasyon oranlarında ise %10 ve %20 oranlarında kalıcı şekil değişimi çok düşük değerlerde olup artan deformasyon oranlarında dikkate değer bir artış görülmüştür.

Anahtar kelimeler: Yüksek yoğunluklu polietilen, Basma, Deformasyon, Sertlik, Gerilme

GRAPHICAL ABSTRACT (If possible)





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1. Introduction

HDPE materials are widely used due to their lightweight, good insulation, easy moldability and cheapness [1]. HDPE materials are one of the semi-crystalline polymers in the polyolefin family. The name of polyethylene comes from the structures that form it, from ethylene monomers. HDPE polymers are more crystalline than the other types of polyethylene like low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE) and cross-linked polyethylene (XLPE). This situation makes HDPE more ductile than the other polyethylenes. These materials can be exposed to mechanical, thermal, ultraviolet rays and chemical factors during use. Some properties may change after the specified factors. The determination of these features is also an important issue.

It has been observed that after the tensile test the tensile strength values of the samples with increasing deformation rates, increase the tensile strength and modulus of elasticity values in contrast to the elongation at break values decrease in the results of the studies in the literature [2]. In another study, it was observed that the thermal aging process of HDPE material increased its mechanical properties, as well as increased hardness values [3]. Harekrushna et al. (2019) mixed HDPE material and polypropylene (PP) material in different ratios by mass in their study. They determined that the speed of testing and surface roughness of the polymer mixtures affect the mechanical properties of materials. Lamri et al. (2020) found out that increasing the strain rate in tension will decrease the molecular mobility of the HDPE chains by making the chains stiffer.

Koriem et al. (2021) pointed out that several researchers have studied the effect of weathering on the chemical and physical properties of polymers. And those researchers found out that degradation affects the physicochemical properties of polymers. In addition, they concluded that additives are very effective for the stability and durability of the polymer matrix.

In this study, different from the studies in the literature, the compression process was applied to HDPE materials and hardness measurements were carried out. Such a process has not been performed before and it is planned to contribute to the literature in this way. Compression process was carried out at 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% deformation rates in the direction of the thickness of HDPE materials. Stress values were calculated for applied compression ratios. The plastic deformations occurring at these rates were calculated by measuring their thickness. The hardness of the samples was measured at the specified compression ratios.

2. Materials and Methods

Petkim I668 was used as HDPE material which is a commercial product in granule form with a melt flow rate of 5.5 g/10 min (190 °C / 2.16 kg). HDPE granule raw material is shown in Figure 1 [7]. HDPE granules were dried in an oven at 60 °C for 4 hours before the injection molding machine. Then, the samples were produced by melting at 170-180-190-200 °C from the feeding zone to the nozzle zone in a plastic injection machine with a screw diameter of 35 mm, L/D ratio of 30 and mold closing power of 70 tons.

Figure 1. HDPE granule raw material

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All the samples were kept in the Nüve brand TK252 model conditioning unit at 23 °C and 50% relative humidity for 40 hours according to the ASTM D618 standard [8] before the tests. The oven, plastic injection machine, conditioning unit and oven are shown in Figure 2 [7].

Figure 2. Devices used in production a) oven, b) conditioning unit and (c) plastic injection machine

Compression processes were carried out in Shimadzu brand AGS-X 100 kN model 100 kN load cell static tensile-compression test device at 1.3 mm/min speed of testing according to ASTM D695 standard [9]. The universal testing machine and compression plates are given in Figure 3 [7].

Figure 3. Shimadzu AGS-X 100 kN universal tensile-compression tester and compression plates

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The required sample dimensions for the compression process are 3±0.2 mm x 13±0.5 mm x 25±0.5 mm. Compression samples were obtained by cutting from ASTM D790 samples [10]. Sample dimensions are given in Figure 4.

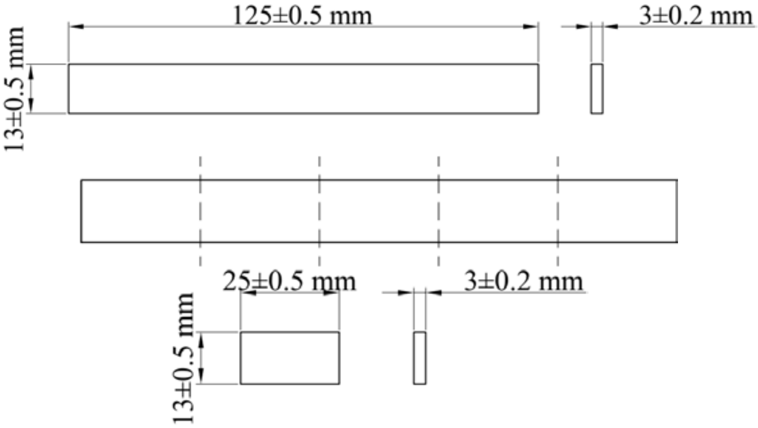

Figure 4. Dimensions of the compression sample

Compression operations were carried out in the direction of the thickness of the samples as shown in Figure 5. Compression ratio were made at the ratios of 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% according to the thickness. Six samples were subjected to the compression process at each compression ratio. Sample codes are given in Table 1.

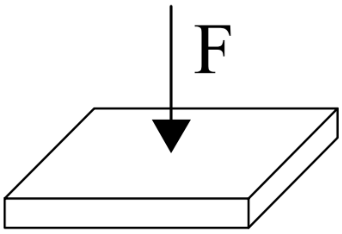

Figure 5. Direction of compression

Table 1. Compression rates and sample codes

Compression ratio (%)	Sample Code
0	HDPE
10	HDPE_10
20	HDPE_20
30	HDPE_30
40	HDPE_40
50	HDPE_50
60	HDPE_60
70	HDPE_70
80	HDPE_80

The stress values in the compression ratios of the compressed samples were determined. In addition, the hardness of the samples at these compression ratios was measured. Hardness measurements were carried out on 6 different samples each compression process using the X.F Shore-D hardness tester [3] (Figure 6) according to the ASTM D2240 standard [11].

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Figure. 6 X.F Shore-D hardness tester

3. Results and Discussions

After compression, plastic deformation rates were measured with a digital caliper and micrometer and calculated as percent change. Compressed and uncompressed HDPE samples are shown in Figure 7. The average, highest, lowest and standard deviation values of the calculated plastic deformation rates are given in Table 2.

Plastic Deformation Rate (%)								
0	10	20	30	40	50	60	70	80

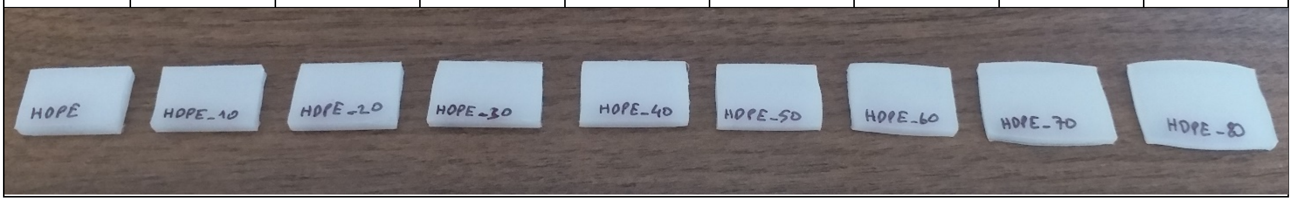

Figure 7. Compressed and uncompressed HDPE samples

Table 2. The calculated plastic deformation rates

Sample Code	Plastic Deformation Rate (%)			
	Average	Max	Min	Standard Deviation
HDPE_10	1.3	1.6	1	0.3
HDPE_20	1.3	1.7	1	0.3
HDPE_30	6.8	8.2	5.7	1.3
HDPE_40	12.7	15.2	11	2.2
HDPE_50	16.2	17.9	13.7	2.2
HDPE_60	28	31	25.7	2.7
HDPE_70	41.8	43.1	40	1.6
HDPE_80	50.5	51.6	49.2	1.2

It has been observed that the plastic deformation is at the same values at 10% and 20% compression rates. It has been determined that the material has not yet reached the yield limit at these rates, in other words, it has not reached permanent deformation. Also, it has been observed that the permanent deformation rates increase with increasing compression ratios above 20%. However, it has been found that these values are not as high as compression ratios. The reason for this is the recovery of the elastic deformation after compression. The calculated plastic deformation rates are shown in Figure 8 comparatively.

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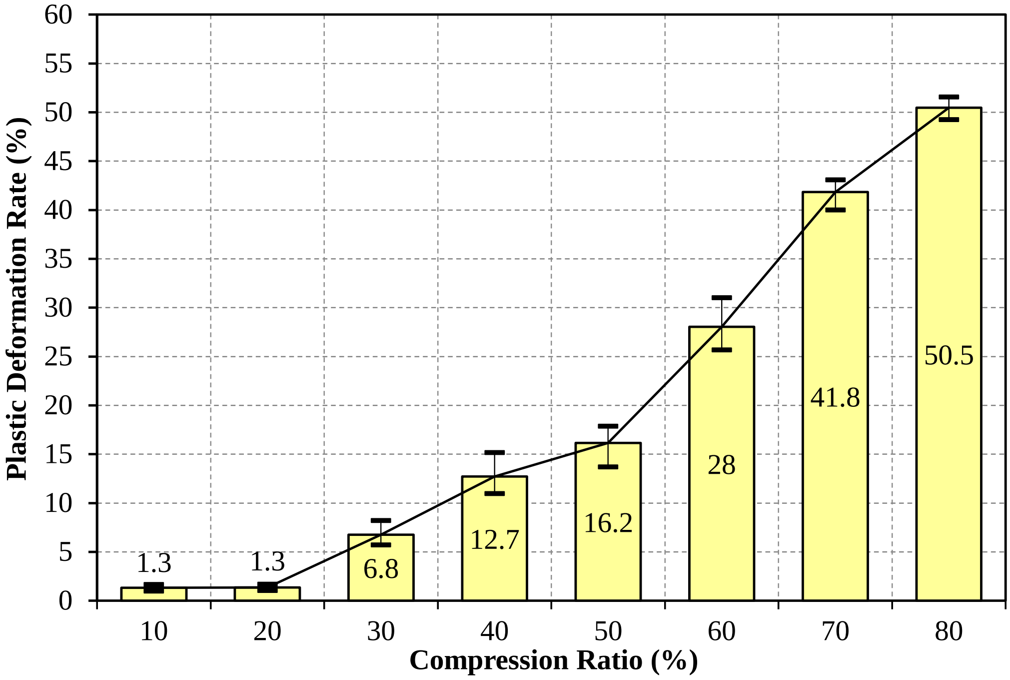

Figure 8. The calculated plastic deformation rates of HDPE materials

The compression curves are shown in Figure 9. It has been observed that the characteristics of the compression curves are in a harmony with each other. The HDPE material could not reach the yield limit up to 20% compression ratio but at increasing strain rates, yield limit values exceeded. The stress values at the determined compression ratios are given in Table 3. The average, highest, lowest and standard deviation values were calculated.

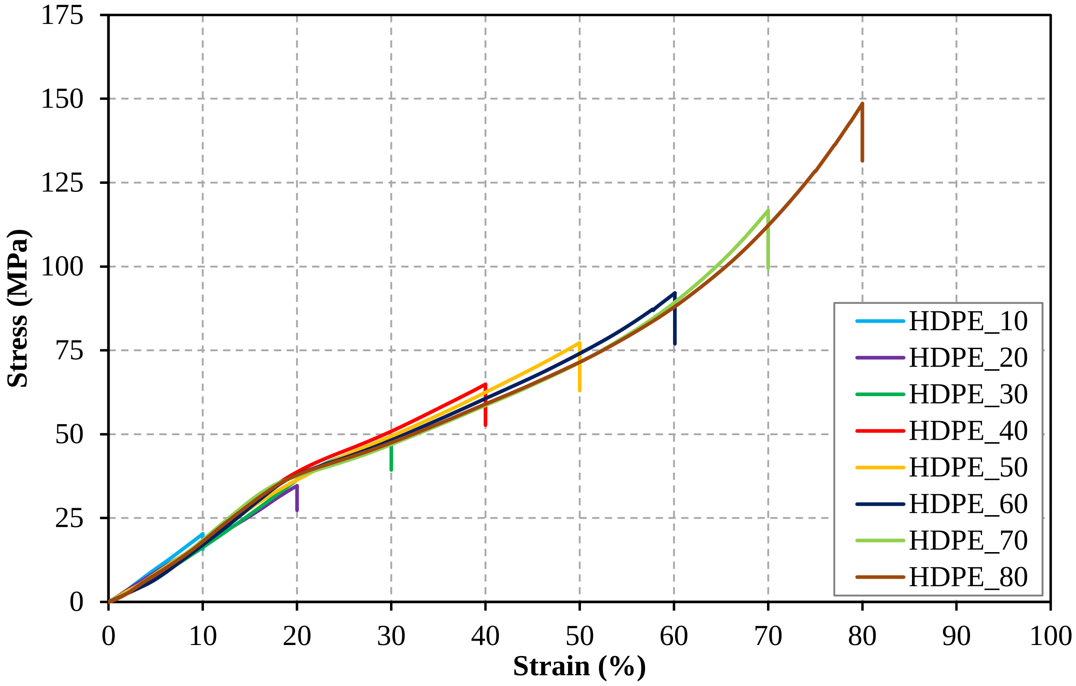

Figure 9. The compression curves of HDPE Materials

Table 3. The stress values of compressed HDPE materials

Sample Code	Stress (MPa)			
	Average	Max	Min	Standard Deviation
HDPE_10	19.8	21.5	18	1.3
HDPE_20	36.7	38.2	35.9	0.9
HDPE_30	52.1	53	51.4	0.6
HDPE_40	65.4	67.2	63	1.5
HDPE_50	77.2	78.5	75.5	1.1
HDPE_60	92.5	93.6	91.2	1.1
HDPE_70	115.8	117.9	114	1.5
HDPE_80	152.2	155.9	149.1	2.5

The stress values at the specified compression ratios are shown in Figure 10 comparatively. It is clearly seen that while a nearly linear increase is observed in the stress values up to 60% compression ratio, the amount of increase is significantly at 70% and above compression ratios.

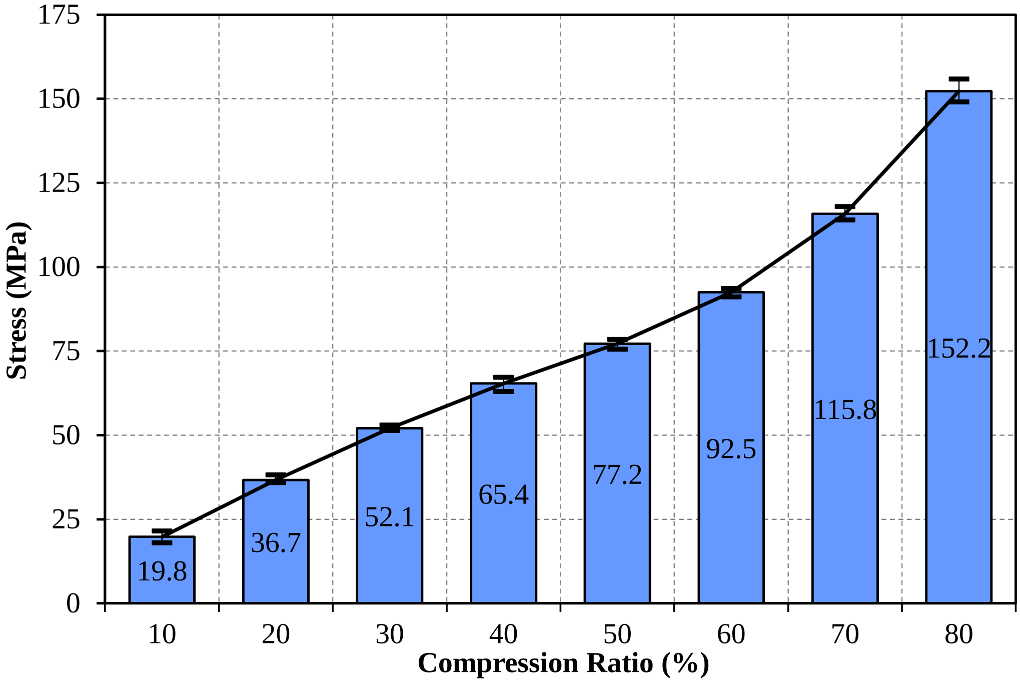

Figure 10. The stress values at specified compression ratios of HDPE Materials

After the hardness tests, mean, highest, lowest and standard deviation values were calculated. These values were given in Table 4. The hardness values were given in Fig. 11 comparatively. The highest hardness value was reached at 10% compression, and it was observed that the hardness values decreased with increasing compression ratios. This is due to the breaking of bonds between HDPE molecules at increasing deformation rates. However, it has been observed that the hardness values are higher than the uncompressed HDPE material at compression ratios between 10% and 50%.

It has been observed that it gives the same hardness values when compared to HDPE material with 60% compression ratio. On the other hand, it was determined that the hardness values at 70% and 80% compression ratios were lower than the hardness values of the materials that were not subjected to the compression process. This situation has shown that increasing deformation rates reduce the hardness values of the HDPE materials.

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Table 4. The hardness values of compressed HDPE materials

Sample Code	Hardness (Shore-D)			
	Average	Max	Min	Standard Deviation
HDPE	61.5	62	61	0.5
HDPE_10	65.9	67	65	0.8
HDPE_20	65.5	66	64	0.6
HDPE_30	64.7	66	64	0.8
HDPE_40	64.1	65	63	0.8
HDPE_50	63.5	64	63	0.5
HDPE_60	61.6	62	61	0.5
HDPE_70	60.2	61	59	0.7
HDPE_80	60	61	59	0.7

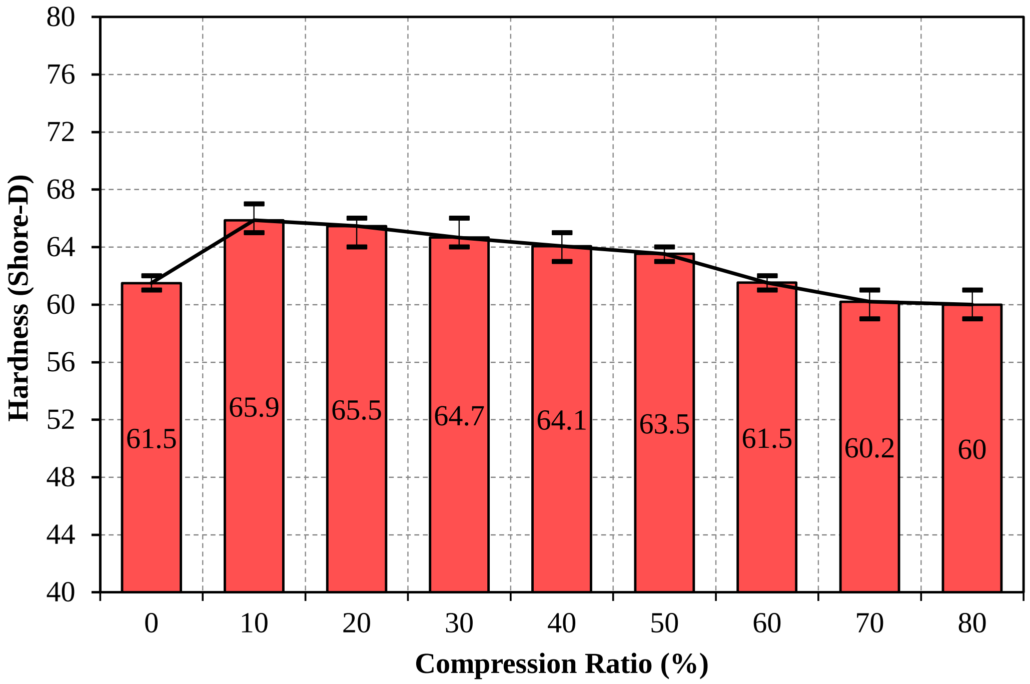

Figure 11. The hardness values at specified compression ratios of HDPE materials

4. Conclusions

In this study 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% compression process were carried out on HDPE materials according to their thickness. Permanent plastic deformation rates and stress values at specified compression rates are given comparatively. Also, hardness measurements of the compressed samples were made and the results were given comparatively.

The following conclusions have been drawn as a result of this study.

- There was no plastic deformation difference observed between 10% and 20% whereas a remarkable change was observed between 30% and 80%.
- It was observed that while the hardness values increased at compression ratios between 10% and 50% but the hardness values decreased at 70% and 80% compression ratios.
- The highest increase in hardness test was observed at 10% compression ratio.

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